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R. D. NEIFELD

JULY 1996

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DEVELOPMENT AND ENGINEERING CENTER
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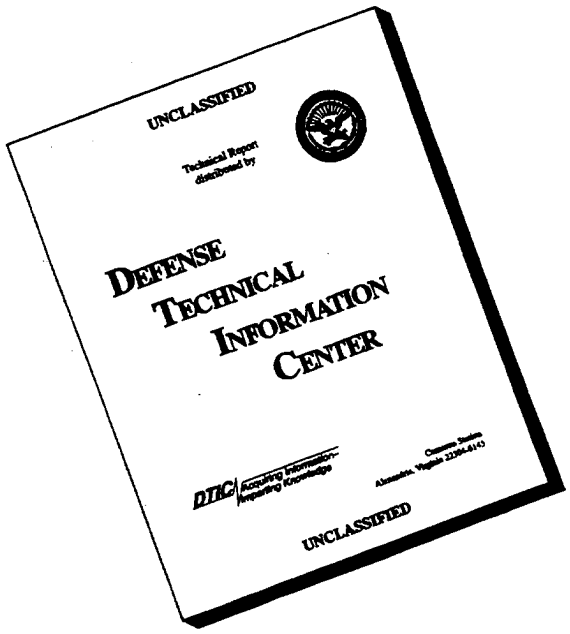

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A SIMPLE AND ACCURATE TECHNIQUE FOR MONITORING CRACK GROWTH BEHAVIOR USING A WAVE FORM ANALYZER

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D. Eric Leighton and Ronald T. Abbott

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13. ABSTRACT *(Maximum 200 words)*

A technique for monitoring the change in compliance of a standard three-point bend specimen during fatigue cycling has been developed. This method allows for accurate measurement of the load-line displacement changes that occur as a crack grows from the notch. The significance of this technique is that it allows accurate determination of crack growth behavior throughout the life cycle of the specimen when a clip gage is impractical or impossible to use.

14. SUBJECT TERMS
Three-Point Bend Specimen, Load-Line Displacement, Crack Growth Behavior, Wave Form Analyzer, Fatigue, Crack-Mouth Opening Displacement

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FATIGUE LIFE AND FRACTURE ANALYSES
FOR THE M185/M284 BREECH RING

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J.H. Underwood, E. Troiano, and A.A. Kapusta

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13. ABSTRACT (Maximum 200 words)

Fracture mechanics and fatigue life analyses were performed for M185/M284 breech rings, with emphasis on ring Serial No. 1659, which failed during safe life testing after 109 pressure cycles. Mechanical and fracture properties from the breech rings were measured and used to perform yield-before-break fracture analysis. Scanning electron fractography was used to determine the size of defect present in ring Serial No. 1659 prior to laboratory testing and the types of cracking that occurred during laboratory testing. Mean fatigue life calculations were prepared for various sizes of defect and applied pressures, including the defect size measured from fractography, the pressure of the laboratory test, and the pressure of the rounds that are fired with this type of breech ring.

14. SUBJECT TERMS
Fatigue Life, Laboratory Tests, Cannon Breech,
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13. ABSTRACT *(Maximum 200 words)*

Fracture mechanics testing and analysis were performed for the long rod penetrator of the 105-mm C76A1 kinetic energy round. Material property and inspection results from the manufacturer of the tungsten alloy penetrator were reviewed. Fracture toughness was measured and bend energy-to-failure tests were performed from each of the five production lots for the penetrator. Analysis of the manufacturer's results and the U.S. Army Armament Research, Development, and Engineering Center's test results failed to identify any defect in the material or manufacturing process that could cause a failure of the type that occurred with one round during firing tests.

A penetrator was fatigue tested so as to produce a 1.6-mm deep crack in the root of its rearmost groove. The bend energy-to-failure of this cracked penetrator was measured to be about one-eighth of that of an uncracked penetrator.

Results of the tests and analyses indicate that a crack of about the same size as that in the fatigue test had been present in the penetrator that failed in firing tests. A recommendation was given to use an eddy-current inspection method in future manufacturing of this type of tungsten alloy penetrator.

14. SUBJECT TERMS
Fracture Mechanics, Tungsten Alloy, Kinetic Energy Penetrator, Nondestructive Inspection, Fracture Toughness

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13. ABSTRACT (Maximum 200 words)

A new technique to evaluate the electrical properties of semiconductor wafers and devices using surface photo-charge voltage (SPCV) measurements is presented. SPCV measures the change in the surface electrical charge induced by a chopped laser light whose photon energy exceeds the band gap energy of the semiconductor sample. This charge is measured capacitatively, thus SPCV measurements do not require the fabrication of metal contacts. In photo-charge voltage spectroscopy measurements, the SPCV is measured as a function of the energy of a sub-band gap monochromatic steady-state illumination, and its derivative spectrum is associated with the density of surface states. A qualitative analysis of the proposed measurement is presented along with experimental results performed on gallium arsenide samples passivated with a thin zinc selenide film of variable thickness. The proposed technique is completely contactless, and it can be used as an in-line nondestructive characterization of semiconductor wafers during the various stages of integrated circuits fabrication.

14. SUBJECT TERMS
Semiconductor Characterization, Surface Charge, Surface States, Zinc Selenide, Spectroscopy

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ADAPTIVE FINITE ELEMENT METHOD III: MESH REFINEMENT

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

An adaptive finite element method is developed to solve initial boundary value problems for vector systems of parabolic partial differential equations in one space dimension and time. The differential equations are discretized in space using piecewise linear finite element approximations. Superconvergence properties and quadratic polynomials are used to derive a computationally inexpensive approximation to the spatial component of the error. This technique is coupled with time integration schemes of successively higher orders to obtain an approximation of the temporal and total discretization errors. The approximate errors are used to control an adaptive mesh refinement strategy. Refinement is performed in space, time, or both space and time depending on the dominant component of the error estimate. Levels of refinement are determined automatically based on the theoretical orders of the numerical methods. Computational results provide an indication of the utility of such a strategy in keeping the total error within a prescribed tolerance.

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14. SUBJECT TERMS
Parabolic Differential Equations, Adaptive Finite Elements, Equidistribution, Linear Stability, Mesh Movement

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13. ABSTRACT *(Maximum 200 words)*

Several medium and high strength alloys, including AF1410, Inconel 718, PH 13-8 Mo stainless steel, and ASTM A723 high strength low alloy steel, have been heat treated to various strength and toughness levels and evaluated for correlations between fracture toughness and Charpy impact energy. The correlations investigated included those by Rolfe-Novak and Ault-Wald-Bertolo. Previous work by Kapp and Underwood suggests that for A723 steel, the Rolfe-Novak correlation predicts the fracture toughness reasonably well. One potential limitation of their study was that the Charpy impact energy was measured at -40°F, whereas the toughness was evaluated at room temperature. This study evaluates Charpy impact energy and toughness at both room temperature and at -40°F and considers both when utilizing these correlations. Results of this study indicate that the Rolfe-Novak correlation overpredicts the measured fracture toughness at room temperature, and tends to underpredict the measured fracture toughness at -40°F. The Ault-Wald-Bertolo correlation, in all but one instance, was a conservative estimate of the measured fracture toughness of the material at both room temperature and -40°F. Utilizing the results presented in this study, it is recommended that if a correlation is necessary for estimating the toughness of any of these materials, the Ault-Wald-Bertolo correlation will result in a conservative estimate of toughness.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Fracture Toughness, Charpy Impact Energy, Yield Strength, Rolfe-Novak Correlation, Ault-Wald-Bertolo Correlation, AF1410, Inconel 718, PH13-8 Mo, A723 Steel	8
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RESIDUAL STRESS EFFECTS AT A NOTCH ROOT IN A723 STEEL TO EXTEND FATIGUE LIFE

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6. AUTHOR(S)
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13. ABSTRACT (Maximum 200 words)

Fatigue life tests were performed with notched bend specimens of ASTM A723 steel with three types of residual stress treatments and resulting residual stress: shot peening, hole swaging, and tensile overload. The three treatments produced widely different depths and surface values of residual stress near the notch root and different fatigue lives depending mainly on the notch root surface value of compressive residual stress. The highest life was measured from overload specimens, which had both the deepest and the highest surface value residual stress distribution. Fracture mechanics-based calculations of fatigue life agreed well with measurements. The calculations accounted for the following factors that affect fatigue life: the crack growth properties of the material; the shallow surface-crack configuration; the applied loading; and the depth and surface magnitude of the residual stress distribution. A consistent description of fatigue life was obtained from a ΔK versus calculated life plot, where the ΔK is for a shallow crack near the notch root and in the region of compressive residual stress. A power-law relationship between ΔK and fatigue life agreed well with the results from both the untreated notches and those with the three types of residual stress, indicating that fatigue life predictions could be made with some confidence for tests under generally similar conditions.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Residual Stress, Fatigue Life, Crack Growth, Notch Root, Shot Peening, Tensile Overload, Hole Swaging, Notched Bend Specimens	16
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4. TITLE AND SUBTITLE
WINDABLE QUASI-GEODESIC PATHS ON SURFACES OF REVOLUTION

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

If r is the profile or radius function for a surface of revolution and r_o is the polar radius function, a quasi-geodesic path on the surface can be defined by the generalized Clairaut relation $rSinw=r_o$, where w is the meridional angle. An inequality involving r, r', r'', r_o, and r_o' is derived. The global satisfaction of this inequality guarantees the windability of the path on a convex ($r''<0$) surface by a filament winding machine. If the surface is concave anywhere ($r''>0$) and a more well known "clinging" inequality is also satisfied, windability is also guaranteed. By "windable" we mean that the winding data produced from the path represents a single-valued function and that the wound filament does not bridge. In addition to this new windability criterion, simplified methods for generating quasi-geodesic paths and properly scaled winding data are also presented.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Filament Winding, Geodesics, Differential Geometry, Surface of Revolution	21
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CHEMICAL ANALYSIS OF GUN STEEL
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AMCMS No. 6126.24.H180

6. AUTHOR(S)
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13. ABSTRACT (Maximum 200 words)

Emission spectroscopy appears to adequately screen noncritical standard stock metals with their wide constituent tolerances. For this work, the Angstrom model V-70 direct reading vacuum emission spectrometer was used to perform computer-assisted chemical characterization of gun steel materials. The development of multi-element calibration data, spectral interference corrections, matrix interference corrections, and system operating condition corrections are discussed. Unfortunately, even fully optimized emission spectroscopy completely fails to chemically characterize critical service intensive metals, such as gun steel, with their narrow constituent tolerances. For gun steel, the respective required concentration ranges (weight percent), required precisions at 95 percent confidence (weight percent), and achieved precisions at 95 percent confidence (weight percent, optimized emission spectroscopy) are: carbon = 0.30 to 0.38, ±0.01, ±0.02; nickel = 2.00 to 3.50, ±0.05, ±0.10; phosphorus = 0.001 to 0.014, ±0.001, ±0.002; sulfur = 0.001 to 0.012, ±0.001, ±0.003; chromium = 0.80 to 1.20, ±0.05, ±0.10; manganese = 0.50 to 0.70, ±0.02, ±0.06; molybdenum = 0.40 to 0.60, ±0.02, ±0.03; vanadium = 0.080 to 0.120, ±0.005, ±0.030; silicon = 0.15 to 0.30, ±0.01, ±0.02; aluminum = 0.001 to 0.010, ±0.001, ±0.005; and titanium = 0.001 to 0.015, ±0.001, ±0.017. Optimized emission spectroscopy inadequately characterizes gun steel to the desired level of precision. Although they are more time-consuming, inductively coupled plasma and carbon/sulfur analyzer benchmark methods are strongly recommended for all future gun steel material analyses due to their very desirable levels of precision.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Chemical Analysis, Gun Steel, Optimized Emission Spectroscopy	28
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13. ABSTRACT (Maximum 200 words)

This report considers the efficient solution of the following problem: given pressure travel shape data for a particular round, compute the rifling curve which will produce a projectile torque curve of virtually any desired shape.

14. SUBJECT TERMS
Rifling, Twist, Progressive, Gain, Torque

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AMMUNITION TEMPERATURE EMULATOR INVESTIGATION FOR THE M1A1 ABRAMS TANK

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

It is a well-known fact that the propellant temperature of a round of ammunition affects the dynamics of a cannon and thus the trajectory of the projectile. As the propellant temperature varies, its burn rate also varies. A faster burning propellant increases projectile velocity, thus affecting range, accuracy, and penetrating capability for kinetic energy projectiles. Muzzle deflections during firing are related to projectile velocities, which in turn relate to the propellant temperature. Therefore, it is necessary to establish a more accurate estimate of the propellant temperature at the time of ignition to account for and minimize muzzle deflection. This report outlines a theoretical approach that can be used to develop an emulator design. An experiment conducted to validate the theoretical approach is also discussed.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Thermal Emulator, Temperature Gage	11
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TRANSLAMINAR FRACTURE TOUGHNESS TEST METHODS AND RESULTS FROM INTERLABORATORY TESTS OF CARBON/EPOXY LAMINATES

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

Fracture tests were performed with carbon/polymer laminates and analyzed for the purpose of developing translaminar fracture toughness test and analysis procedures. Notched specimens were tested on two types of symmetrical layups, quasi-isotropic [0/45/90] and [0/90]; two carbon fiber/epoxy materials, a relatively brittle T300 fiber/976 epoxy and a tougher AS4 fiber/977-2 epoxy; two laminate thicknesses, 2-mm and 4-mm; and three specimen configurations, the standard three-point bend and compact configurations, and an extended compact specimen with arm height-to-specimen width ratio of 1.9. Stress and displacement expressions were obtained for the extended compact specimen, including those for stress intensity factor, K, and crack-mouth opening displacement, V, in terms of relative notch length, a/W, and for a/W in terms of V. Relationships for the bending stresses that control self-similar and off-axis cracking for the extended compact specimen were also derived.

Damage was characterized in the tests, including that associated with arm breakage in the standard compact specimen and load-point damage in the bend specimen. Two types of notch-tip damage were characterized using radiography, that which extends perpendicular to the notch in predominantly 0° fiber layups, and that which occurs ahead of the notch in quasi-isotropic and 90° fiber layups. The applied K at maximum load, K_{max}, determined in a way that took account of the effective crack growth up to the maximum load point, was used as a measure of fracture toughness. For deviations from the linear P-V plot corresponding to $\Delta a/W \leq 0.04$, K_{max} gave consistent measurements of fracture toughness. This criterion also excluded tests with damage of the type that violates the basic concept of fracture toughness measurement, including the arm breakage and load-point damage noted in the tests. Plots of K_{max} versus $\Delta a/W$ showed increasing resistance to crack growth for quasi-isotropic layups and constant resistance to crack growth for predominantly 90° fiber layups.

14. SUBJECT TERMS
Fracture Toughness, Laminated Composites, Carbon/Epoxy, Notch-Tip Damage, X-ray Radiography, Translaminar Fracture, Specimen Configuration

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

Conventional tank battles are an important aspect of current and future warfare techniques. Even though our mechanized weaponry is extremely accurate, we should not embrace the mindset that the best in tank gun accuracy has been achieved. We can should embrace the mindset that the best in tank gun accuracy has been achieved. We can and should do more! The 'fleet zero' concept brought about by the downsizing trend in today's army means that zeroing exercises will be conducted for the entire fleet using only a few tanks and gun tubes. The contribution of individual tubes to a tank's accuracy is no longer determined. Therefore, for the concept to work, variability in tube-to-tube manufacture (or more importantly the variability that contributes to accuracy) must be minimized or accounted for through the use of computer simulation. This report presents a comprehensive study into the relationship among the characteristics of gun tubes, projectiles, gun mounts, and ballistics and their effect upon dynamics at the muzzle and shot accuracy. The data is provided from the dynamic index tube test conducted in the early 1990s. Modelling is performed using Benét's gun vibration model and a recently purchased gun vibrations code. The overall goal is to provide aiming point correction factors based upon system dynamics and an empirically determined exit jump offset for a specific round and ballistic load. In this type of analysis, the values of uncertain or unknown parameters are randomly drawn from an expected statistical distribution. Therefore, a given distribution of input values results in a distribution of output responses having its own characteristics. The likelihood that a response occurs is cast in terms of a probability distribution. For the test data used and the analysis run, fifty percent of the samples show promise for the use of this semi-elliptical method of shot impact prediction. Further study including more rounds and gun tubes is recommended with the intent of gaining improved accuracy across the full family of rounds for the M1A1 tank.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Gun Dynamics, M1A1, Tank Gun Accuracy, Modal Analysis, Probabilistic Analysis, M256 Tank Cannon, Kinetic Energy Projectile	94
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FATIGUE LIFE MEASUREMENTS AND ANALYSIS FOR OVERSTRAINED TUBES WITH EVACUATOR HOLES

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6. AUTHOR(S)
John H. Underwood, Anthony P. Parker (University of Northumbria at Newcastle, UK), Daniel J. Corrigan, and Michael J. Audino

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13. ABSTRACT (Maximum 200 words)

Sections of cannon tubes with inner radius of 53, 60, and 78 mm were cycled from near zero to 100 to 300 MPa internal pressure until fatigue failure occurred. The failure locations were along 2-mm holes cut through the cannon wall at a 30° angle to the tube axis, for the purpose of evacuating combustion gases from the cannon after firing. The cannons had various amounts of autofrettage by overstraining, including 0, 30, 50, and 100 percent. The amount of overstrain affected both the initiation position of the fatigue crack along the evacuator hole and the measured fatigue life. Increasing the amount of overstrain moved the crack initiation from the tube inner radius toward a mid-wall position and significantly increased fatigue life.

Fracture mechanics and solid mechanics-based calculations of fatigue life were performed for comparison with the measured lives. The calculations gave a good description of the measured life, taking account of tube configuration, applied pressure, amount of overstrain, stress concentration of the hole, crack size and shape, material fatigue crack rate behavior and yield strength, and pressure in the hole and on the crack surfaces. As with measured fatigue life, the calculated life was significantly affected by the amount of autofrettage of the tube. The ratio of outer-to-inner radius of the tube and the presence of pressure in the evacuator hole also had substantial effects on the calculated fatigue life.

14. SUBJECT TERMS
Fatigue Life, Thick-Wall Cylinder, Residual Stress, Pressure Vessel, Stress Concentration

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13. ABSTRACT *(Maximum 200 words)*

This report, in conjunction with its multivector analysis package, provides: (1) a brief introduction to the ideas and features of the 8-dimensional geometric algebra G(3) defined on 3-space; (2) a code for performing geometric algebra analysis; (3) examples of the operation of the code; and (4) applications of geometric algebra to the solution of multivector equations and to rotation operations in 3-space.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Mathematica, Geometric Algebra, Multivector Algebra	36
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13. ABSTRACT (Maximum 200 words)

A monitor has been designed to detect the onset of *status epilepticus* associated with complex partial seizures in children. A unique sensor technology was developed to detect the minor, barely perceptible tremors characteristic of partial seizures. A microcontroller analyzes the sensor data and activates a remote tetherless alarm when a seizure is detected. However, the sensor response is similar for both casual and seizure activity, therefore, false alarms do occur. Neural networks have been studied as a means of analyzing the sensor response and differentiating seizure activity from casual motion. The network uses elements of the normalized power spectrum of the response data as a feature set. Our results indicate this approach provides a faster and more reliable means of accurately detecting seizures than the method currently employed.

14. SUBJECT TERMS
Epilepsy, Neural Networks, Seizures, Monitor, *Status Epilepticus*

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IMPLEMENTING TENSOR ANALYSIS IN *Mathematica* WITH ILLUSTRATIONS FROM SCHWARZCHILD GRAVITATION

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13. ABSTRACT (Maximum 200 words)

Expressions that play roles in tensor analysis, such as Christofell symbols and curvature tensors, are coded as *Mathematica* modules by straightforward transcription of their defining equations. The built-in functions can then be used to perform tensor analysis and numerical valuations. The utility of the *Mathematica* formulation is illustrated by examples from Schwarzchild gravitation.

14. SUBJECT TERMS
Mathematica, Tensor Analysis

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4. TITLE AND SUBTITLE
AN EXPERIMENTAL INVESTIGATION OF THE GASDYNAMIC PERFORMANCE OF GUN BORE EVACUATORS MOUNTED ON 155-MM SELF-PROPELLED HOWITZERS

5. FUNDING NUMBERS
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6. AUTHOR(S)
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11. SUPPLEMENTARY NOTES
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13. ABSTRACT *(Maximum 200 words)*

The charge and discharge cycles of the 155-mm gun bore evacuator have been investigated at the Rensselaer Polytechnic Institute (RPI) High Pressure Shock Tube and Steady-State Flow Facilities. To test the charge and discharge phases in the high pressure shock tube, a 65 percent scale model of the bore evacuator is installed on the end of the shock tube. Thin plastic diaphragms are placed over the evacuator charge and discharge ports. The pressure behind the Mach 1.89 incident shock wave is 91 psia, and the flow Mach number is 0.89. The evacuator pressure is varied to obtain ratios of the initial evacuator pressure-to-bore pressure up to 2300. The charge coefficient for the charge ports in the baseline configuration is 0.29. With no restriction at the exit of the charge ports, the charge coefficient is approximately 0.40. The charge coefficient for the angled discharge ports varies from 0.51 at a P_p/P_e of 4 to 0.58 at a P_p/P_e of 1570. During the charge phase with high pressure ratios across the evacuator ports, shock waves with high temperatures behind the waves are present in the evacuator. The discharge coefficient for the ejector ports is approximately 0.72 for an evacuator pressure range of 50 to 195 psia. A 33 percent scale model of the 155-mm gun bore evacuator is installed in the RPI Steady-State Flow Facility, and the performance of a model with six staggered ejector ports is compared to the baseline configuration. The staggered ejector configuration results in a gain of approximately 20 percent in the mass flow augmentation ratio over test pressures from 1 to 84 psig. The discharge coefficients for the baseline and staggered ejectors are nearly constant at approximately 0.80 for evacuator pressures greater than 26 psig, and the coefficient drops off rapidly at pressures lower than 16 psig.

14. SUBJECT TERMS
155-mm Self-Propelled Howitzer, Gas Dynamics, Model Bore Evacuator Performance, Staggered Ejector Nozzles, Shock Tube, Reservoir Charge-Up, Quasi-Steady-State Discharge Coefficient, Mass Flow Augmentation Ratio, Velocity, Mach Number Distribution, Thin-Film Platinum Heat Gauge

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INVESTIGATION INTO ANALYSIS AND DESIGN OF FILAMENT WOUND COMPOSITE GUN BARRELS

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6. AUTHOR(S)
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11. SUPPLEMENTARY NOTES
Kevin Miner - Benet Laboratories Project Engineer

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13. ABSTRACT *(Maximum 200 words)*

Experimental and theoretical investigations into filament would composite gun barrels were performed. A technique for calculating the elastic strains that develop as a result of gun barrel manufacture and field use is presented. Numerical results were obtained for several cases. They show that a significant residual stress state will exist because of the filament winding processing technique. Furthermore, depending on the lay-up and cure cycle, large localized stresses can be generated which could cause defects such as longitudinal wrinkles. Several possible solutions are presented. A simple technique for measuring the tension during filament winding was developed and used to optimize the winding process. Tension levels up to 7 pounds were employed successfully in the experiments. The use of such high tensions leads to wrinkle free cylindrical structures for the IM7/epoxy composite system.

14. SUBJECT TERMS
Filament Winding, Composites, Gun Barrels, Elastic Strains, Residual Stress, Epoxy, Wrinkles

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FRACTURE MECHANICS CHARACTERIZATION OF WELDS:
FATIGUE LIFE ANALYSIS OF NOTCHES AT WELDS;
J_{Ic} FRACTURE TOUGHNESS TESTS FOR WELD METAL

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

In this report two methods of fracture analysis of welds will be emphasized, one addressing fatigue life testing and analysis of notches at welds, and the other addressing the final fracture of the welded component and the fracture toughness tests used to characterize final fracture. These fatigue and fracture methods will be described by referring to recent work from the technical literature and from the U.S. Army Armament Research, Development, and Engineering Center, primarily fracture case study and fracture test method development investigations. A brief general summary will be given of fatigue and fracture methods and concepts that have application to welded structures. Specific fatigue crack initiation tests and analysis methods will be presented, using example results from a welded stainless steel box beam of a cannon carriage. Recent improvements and simplifications in J-integral fracture toughness tests will be described, particularly those related to welds. Fracture toughness measurements for various stainless steel weld metals and heat treatments will also be described.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Fracture Mechanics, Welds, Fatigue Life, J-Integral Fracture Toughness, Notch Stresses	23
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FRACTURE TESTING OF METALS AND COMPOSITES: TESTS AND ANALYSES FOR FAILURE PROBLEMS WITH ARMAMENT COMPONENTS

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6. AUTHOR(S)
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13. ABSTRACT (Maximum 200 words)

Fracture tests have been broadly applied to failure of armament, including failures caused by each of the three general types of fracture--fast fracture, fatigue cracking, and environmentally-assisted cracking. This report describes some fracture mechanics tests and related analyses that have been useful to characterize fracture in armament components made from high strength steels and carbon/epoxy laminates. These include J-integral fracture toughness, notch fatigue life, and environmentally-assisted cracking tests and analyses for steels and linear elastic fracture toughness tests for laminates.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Fracture Mechanics, Fracture Tests, Structural Metals, Composite Materials, J-Integral Fracture Toughness, Fatigue Cracking, Environmental Cracking	23
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NONDESTRUCTIVE EVALUATION OF SPUTTER-DEPOSITED TANTALUM CARBIDE REFRACTORY COATINGS

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

Desirable characteristics of refractory coatings for future projectile launchers include high wear resistance, high melting point, hardness, electrical conductivity, good adhesion, thermal stability, and high plasma resistance properties. Sputtered tantalum and tantalum compounds, such as tantalum nitride and tantalum carbide are being considered as future coatings to endure the high pressure, high temperature, and aggressive chemical environment of the bore. In this work, tantalum and tantalum carbide were reactively sputtered-deposited from argon plasmas containing methane. Nondestructive x-ray diffraction analysis determined that body-centered-cubic (*bcc*) tantalum was deposited at methane concentrations below 20 percent, face-centered-cubic (*fcc*) tantalum carbide was deposited at methane concentrations above 25 percent, and a mixture of tantalum and tantalum carbide was deposited at the transitional 22 percent methane concentration. Coating composition, crystalline structure, particle size, preferred orientations, deposition rate, Knoop hardness, and temperature coefficient of resistivity are sensitive functions of percentage methane concentration in the sputtering-deposited process.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Tantalum, Tantalum Carbide, Sputtering Deposition, Refractory Coatings	21
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MULTIFRACTAL ANALYSIS OF IMPRECISE DATA:
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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

Analytic and numerical implementations of the correlation integral and the Badii-Politi multifractal analysis algorithms are described and applied to machine precision and imprecise model multifractal data. The correlation integral technique yields good results for machine precision data and for data with 1 percent random errors. The *standard* numerical Badii-Politi algorithm did not yield satisfactory results for data with 0.05 percent or larger random errors. However, the present results suggest that a natural generalization of the Badii-Politi approach along the lines suggested by Kostelich and Swinney can be applied to the analysis of imprecise fractal data.

14. SUBJECT TERMS
Fractal, Multifractal, Correlation Integral, Imprecise Data

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13. ABSTRACT *(Maximum 200 words)*

In this report, the effects of ion implantation on two kinds of electroplated chromium have been studied. Both hard chromium and low contraction chromium were plated onto samples of 4340 grade steel and subsequently implanted with N_2^+ or Ar^+ at atom energies of 75 keV. The dose was varied from 9.4×10^{15} to 3.1×10^{18} atoms/cm^2 and the implantations were conducted at both room temperature and 500°C. SIMS and AES analyses, Knoop microhardness, and pin-on-disk wear testing were used to study the effects of ion implantation on the surface properties of the chromium plating.

The greatest improvement in the properties was observed for the nitrogen implantations. In general, the hardness, wear, and friction properties improved with an increasing nitrogen dose. For both kinds of chromium, the nitrogen implantation resulted in a 50% reduction in the coefficient of friction and a measurable decrease in the wear rate. At the intermediate doses tested, some of the samples implanted with nitrogen at elevated temperature showed improved friction and wear properties compared to the room temperature samples implanted at the same condition. The elevated temperature implantations also appeared to decrease the hardness of the bulk chromium. For the room temperature, nitrogen implantations, the hardness was increased three times that of the unimplanted hard chromium and slightly less than twice that of the unimplanted low contraction chromium. At the highest dose tested, the maximum nitrogen concentration reached approximately 40 at% for both the room and elevated temperature conditions.

14. SUBJECT TERMS
Ion Implantation, Chromium, Electroplating, Material Properties, Nitrogen, Friction, Wear Properties

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LOW CYCLE NOTCHED FATIGUE BEHAVIOR AND LIFE PREDICTIONS OF A723 HIGH STRENGTH STEELS

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6. AUTHOR(S)
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13. ABSTRACT (Maximum 200 words)

Two types of ASTM A723 steels have been investigated for their low cycle fatigue behavior (less than 10^4 cycles to failure). Specimens were tested in four-point bending, both with and without notches, and the measured fatigue lives were compared with those predicted by Neuber notch analysis (classic and elastic/plastic remote applied loading), and standard fracture mechanics life prediction techniques. Comparison of measured and predicted lives indicates that the elastic/plastic Neuber analysis underpredicts the measured fatigue life by as much as 67 percent at large strains, and becomes a better predictor of life as the applied strains decrease. The elastic Neuber analysis also underpredicts the measured fatigue lives by 45 percent at large applied strains, but seems to accurately predict lives at reversals-to-failure greater than 100. The fracture mechanics approach assumes elastic stresses at the crack tip, and predicts lives within 30 percent over the full range of strains investigated.

The results show that the Neuber notch analysis is not as good an indicator of the low cycle fatigue behavior of A723 steels as is the fracture mechanics life prediction technique. As the life cycles-to-failure decreases, the Neuber analysis predicts lives that are two to three times more conservative than those experimentally measured. Since the fracture mechanics approach and the elastic Neuber approach are fully elastic stress-based, one can conclude that for this class of steels, an elastic-based life predictions technique works even through we are believed to be in a plastically-dominated regime.

14. SUBJECT TERMS
Low Cycle Fatigue, Life Predictions, Neuber Notch Analysis, A723 Steel, Fracture Mechanics Life Prediction

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ULTRASONIC CULVERT THICKNESS DETERMINATION

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

This work describes a response to the need for a practical non-destructive method of measuring the thickness of culverts in situ established at the New York State Department of Transportation. The proposed method will provide data to realistically evaluate the remaining safe lives of the culverts. The technique developed uses the ultrasonic pulse-echo technique with commercial off-the-shelf ultrasonic equipment and piezoelectric transducers in a bubbler configuration. The equipment consists of the 25DL precision thickness gage and the B120 bubbler with V316-B, 0.75-inch PTF, 20 MHz transducer--all by Panametrics. The user has to add a small water pump to provide continuous stream of water and a hollowed-out rubber stopper to ease application of the bubbler to the culvert surface.

14. SUBJECT TERMS
Ultrasonics, Squirter Technology, Bubbler Technology, Thickness Measurement, Dimensional Measurement, Time Measurement

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CONVERGENCE OF NUMERICAL BOX-COUNTING AND CORRELATION INTEGRAL MULTIFRACTAL ANALYSIS TECHNIQUES

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6. AUTHOR(S)
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13. ABSTRACT (Maximum 200 words)

A systematic study of the rate of convergence for a numerical box-counting and a numerical correlation integral algorithm applied to Euclidean point sets, Koch constructions, and a symmetric chaotic mapping is described. The number of points N_5 required for 5 percent convergence of the box-counting (for $0 \le q \le 25$) and correlation integral (for $-25 \le q \le 25$) algorithms for the fractal sets studied is determined by the generalized dimension D(q) and is given by $\log_{10}(N_5) \approx 2.54\ D(q) - 0.11$. Approximately 25 times as many points are required for 1 percent convergence. The box-based correlation integral (BBCI) algorithm employed in the present studies, which is well suited to the analysis of large data sets, is also described.

14. SUBJECT TERMS	15. NUMBER OF PAGES
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THE RELATIONSHIP BETWEEN RESIDUAL STRESS AND HARDNESS AND THE ONSET OF PLASTIC DEFORMATION

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13. ABSTRACT *(Maximum 200 words)*

The stress distribution in the wall of a hollow steel cylinder that had been autofrettaged varies from compressive at the inside diameter to tensile at the outside diameter. The question of how the Rockwell-C (R_C) hardness varies with residual stress was treated previously. In order to generalize the previously developed concepts, in this report the hardness in the wall was measured as a function of radial position using various hardness testers. Each of the hardness testers used a different applied load to indent the sample surface to measure its hardness. The residual stress of the sample was measured using ultrasonic techniques. From a model proposed by Frankel, Abbate, and Scholz, the relationship between the residual stress and the onset of plastic deformation was derived, and the experimental dependence of R_C on residual stress was shown. From previous work we saw that the effect of residual stress on measured hardness stems from the effect of stress on the onset of plastic deformation: plastic deformation is delayed and hardness is increased for a compressive residual stress, and plastic deformation is enhanced for a tensile residual stress, therefore the measured hardness is decreased. From this work, we see that the effect is detectable for the tests using larger loads, R_C and Rockwell-D (R_D), and becomes washed out for the tests using lower loads (i.e., less total plastic deformation). The Rockwell-A (R_A) and the Microdur® testers using Vickers indenters did not show the hardness dependence on residual stress. We point out that (a) Rockwell-C and Rockwell-D hardness tests on gun steel should be done with an awareness that residual stress can affect the results, and (b) careful Rockwell-C and Rockwell-D tests can be used to obtain residual stress distribution.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Residual Stress, Hardness, Plastic Deformation, Yield Criteria, Ultrasonic Inspection	28
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UNIFIED COMPUTER MODEL FOR PREDICTING THERMOCHEMICAL EROSION IN GUN BARRELS

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

The first known gun barrel thermochemical erosion modeling code is presented. This modeling code provides the necessary missing element needed for developing a generalized gun barrel erosion modeling code that can provide analysis and design information that is unattainable by experiment alone. At the current stage of code development, single-shot comparisons can be made of either the same gun wall material for different rounds or different gun wall materials for the same round. This complex computer analysis is based on rigorous scientific thermochemical erosion considerations that have been validated in the reentry nosetip and rocket nozzle community over the last forty years. The 155-mm M203 Unicannon system example is used to illustrate the five module analyses for chromium and gun steel wall materials for the same round. The first two modules include the standard gun community interior ballistics (XNOVAKTC) and nonideal gas thermochemical equilibrium (BLAKE) codes. The last three modules, significantly modified for gun barrels, include the standard rocket community mass addition boundary layer (TDK/MABL), gas-wall chemistry (TDK/ODE), and wall material ablation conduction erosion (MACE) codes. These five module analyses provide recession, temperature, and heat flux profiles for each material as a function of time and axial position. In addition, this output can be coupled to FEA cracking codes. At the peak heat load axial position, predicted single-shot thermochemical wall erosion showed uncracked gun steel eroded by a factor of one hundred million more than uncracked chromium. For chromium plated gun steel, with its associated crack profile, it appears that gun steel ablation at the chromium cracks leaves unsupported chromium, which is subsequently removed by the high-speed gas flow.

14. SUBJECT TERMS
Unified Computer Model, Thermochemical Erosion, Erosion Prediction, Gun Barrel Design, Thermochemical Ablation, Mechanical Erosion, High Pressure and Temperature, High-Speed Reacting Chemical Flow, 155-mm M203 Unicannon System Example

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WAVELET TRANSFORM SIGNAL PROCESSING APPLIED TO ULTRASONICS

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

The wavelet transform is applied to the analysis of ultrasonic waves for improved signal detection and analysis of the signals. In instances where the mother wavelet is well defined, the wavelet transform has relative insensitivity to noise and does not need windowing. Peak detection of ultrasonic pulses using the wavelet transform is described and results show good detection even when large white noise was added. The use of the wavelet transform to extract the frequency dispersion relation of the Lamb wave velocity is also described. The two-dimensional wavelet transform allows for both time and frequency analysis, thus making it particularly suitable for dispersion studies. Experimental and numerical results show the superior performance of the wavelet transform signal processor.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Wavelets, Signal Processing, Ultrasonics, Flaw Detection, Time-Frequency, Dispersion	23
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ONLINE CHARACTERIZATION OF CRITICAL LOW CONCENTRATION CONSTITUENTS IN CHROMIUM PLATING PROCESS SOLUTIONS

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

The metal plating industry is constantly looking for better online procedures to monitor critical process constituents and increase plating quality and efficiency. The advantages of online monitoring include direct sampling, process control, bath quality control, data processing, hazardous waste monitoring, chemical reclamation monitoring, and chemical additions. These advantages reduce costs, manpower, and downtime, and improve quality. Three new online titration procedures were developed, tested, and evaluated for the monitoring of sulfuric acid, Cr(III), and Fe(III) in chromium plating solutions. Likewise, one new online titration procedure was developed, tested, and evaluated for the monitoring of Fe(II) in electropolishing solutions. These methods were developed at Benet Laboratories and were tested at Brinkmann Instruments, Inc. (Westbury, NY). In general, these four new online procedures from above are Cr(VI) reduction then ion-selective potentiometric, direct colorimetric, Cr(VI) reduction then complex-formation colorimetric, and direct redox titrations, respectively. The optimum operating tolerances of these four chemical species are 2.5 to 3.5 g/L, 0 to 7.5 g/L, 0 to 7.5 g/L, and 0 to 7.5 g/L, respectively. The first chemical constituent is purposely added, while all other constituents are unwanted low alloy steel plating process by-products. Chromium plating solutions also contain 230 to 270 g/L chromic acid. Electropolishing solutions also contain 640 to 730 g/L phosphoric acid and 795 to 895 g/L sulfuric acid. Critical low concentration chemical constituents in the chromium plating process are rapidly monitored using these online titration procedures. These new procedures nearly equal precision and bias of previous offline procedures. The precision, bias, and reliability of these new procedures should be further tested and evaluated for at least a year before adoption. These new online procedures marginally-to-adequately determine critical low concentration constituents in chromium plating process solutions.

14. SUBJECT TERMS
Online Chemical Characterization, Online Automatic Titration, Chromium Plating Process Solutions, Critical Low Concentration Constituents, Chromium Plating Solutions, Sulfuric Acid, Trivalent Chromium, Trivalent Iron, Electropolishing Solutions, Divalent Iron

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13. ABSTRACT *(Maximum 200 words)*

Calculations of the likelihood of a safe, yield-before-break fatigue failure and of the expected mean fatigue life at various locations of the 155-mm XM297 cannon tube are described. Yield-before-break calculations are based on the fracture toughness and yield strength properties of two types of ASTM A723 steel. The mean fatigue life calculations are performed for muzzle brake and bore evacuator holes, the evacuator and mount interface notches, the coolant channels, the coolant entry ports, the thread sector notches, and the chamber inner radius. Effects of pressure, autofrettage residual stress, local residual stress, and notch depth and root radius are accounted for in the calculations. Comparisons are made with measured mean fatigue lives from recent hydraulic pressure safe service fatigue life tests of similar cannon tubes. Environmental cracking in areas of coolant access is also assessed. Based on the life calculations and comparisons with mean life from tests, two sets of notches on the tube outer diameter and the coolant channels at midwall are identified as locations of minimum expected mean fatigue life for the cannon tube. Recommendations are given to accomplish an increase in mean fatigue life at these locations.

14. SUBJECT TERMS
Fatigue Life, Fracture, Stress Concentration, Cannon Tubes, Residual Stress

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AN EXPERIMENTAL INVESTIGATION OF THE BOLT-LOOSENING PROBLEM RELATIVE TO THE 120-MM MORTAR DUE TO SHOCK LOADING

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

The current investigation deals with a solution to the age-old problem of bolt loosening due to excessive vibration and shock loading. Traditionally, this problem is solved by using some combination of pressure washers and especially designed bolts. In the present work, these traditional measures were found inadequate for the problem at hand (the 120-mm M285 system), and the problem was solved by using a combination of inserts and bolt-head wiring. The report also advances some ideas on the nature of the bolt-loosening mechanism.

14. SUBJECT TERMS
Bolt Loosening, Shock and Vibration, Bolt-Head Wiring, Bolt Loosening Due to Shock, Bolt Inserts

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EVALUATION OF HIGH STRENGTH MATERIALS FOR THE REGENERATIVE LIQUID PROPELLANT GUN PROGRAM

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

Four high strength materials, ASTM A723, PH 13-8 Mo, AF 1410, and Inconel 718, were evaluated for the Regenerative Liquid Propellant Gun (RLPG) Program. Experimental heat treatments, mechanical property tests, and environmentally-assisted cracking tests were conducted as part of this investigation.

Environmentally-assisted cracking tests were conducted with constant-displacement bolt-load modified compact specimens in XM46 liquid propellant (LP) at both ambient and slightly elevated temperatures (175°F). The duration of testing was six months and five hours, respectively. Tests were conducted with the solution refreshed at regular intervals and also with the solution unchanged for the duration of testing.

Environmentally-assisted cracking test results indicated that no macroscopic crack extension took place in any of the materials tested in both ambient and slightly elevated temperature (175°F) XM46 LP. Because no macroscopic cracking took place, a valid K_{IEAC} value could not be determined. Hence, none of the materials tested were highly susceptible to XM46 LP for the given test conditions. However, some of the six-month ambient temperature tests conducted on A723 and an experimental heat treatment of AF 1410 showed evidence of microcracking. This environmental attack indicated the potential susceptibility of those materials in XM46 LP.

14. SUBJECT TERMS
Regenerative Liquid Propellant Gun, XM46 Liquid Propellant, High Strength Materials, Environmentally-Assisted Cracking, Stress Corrosion Cracking, Mechanical Properties

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13. ABSTRACT (Maximum 200 words)

An exploratory prototype multi-lug breech block/ring assembly was designed for future projectile launchers. The new geometry redistributes the applied load to several surfaces rather than one surface in conventional breech to react the load. Induced residual stresses from shot peening and overload processes improve fatigue life of the system. In this work, experimental x-ray diffraction residual stress mapping was performed in the lugs of the unaffected portion of a 50 percent overloaded multi-lug breech ring that was fatigue tested to failure. Finite element modelling of a two-dimensional cross section of the breech block/ring assembly was performed using ABAQUS codes on a Convex C-220 computer. Comparisons of experimental residual stresses and finite element analysis (FEA) predictions showed good agreement in the major features of residual stress distribution, especially in the front lug. While FEA predicted the general characteristics of experimental residual stress distribution, experimental residual stresses were deeper and less compressive.

14. SUBJECT TERMS
Multi-Lug Breech, Breech Mechanism, Overload Process, EX35, Residual Stress, Finite Element Analysis

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13. ABSTRACT (Maximum 200 words)

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13. ABSTRACT *(Maximum 200 words)*

We present interpolating functions which have three orders of differentiability at each (convex) data point. These functions are defined as piecewise conics and are therefore guaranteed to be convex in the case of (strictly) convex data. The modifier "affine" refers to the fact that we make no use of Euclidean distance or angle in the discussion. We also include a discussion of numerical differentiation using conics. The nodal derivatives for the conic splines satisfy a locally quadrivariate quadratic system solved by Newton iteration--each iteration involving the solution of a pentadiagonal linear system. Initial values for Newton iteration are obtained by the aforementioned conic numerical differentiation. A discussion of numerical quadrature based on conic splines is also included, as well as a discussion of what we refer to as "sketched" interpolation, which makes use of the mathematical machinery behind conic differentiation and local C^3 conic splines. Sketched interpolation is more generally applicable than global C^3 conic splines are, as well as being computationally simpler, more flexible, and smoother in a local pointwise sense. This apparent increase of smoothness beyond C^3 is obtained through a process of re-sketching during the construction of the interpolant. Sketched interpolants reproduce conics with or without re-sketching. This is to say that if the discrete data comes from a conic, all the points of the sketched interpolant will lie on that conic.

14. SUBJECT TERMS
Spline, Conic, Interpolation, Affine Space, Affine Geometry, Numerical Differentiation, Numerical Quadrature, Abridged Notation

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FRACTURE MECHANICS TESTS AND DEFECT CRITERIA FOR THE 120-MM M121 MORTAR BASEPLATE

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

Calculations of firing stress at several locations of the 120-mm M121 mortar baseplate were made based on available strain gage data. Measurements of fracture toughness were performed for seven weld and heat-treat conditions of the 4130 steel used for the baseplate. Calculations were made of the ratio of applied K to the critical K for fracture for various combinations of firing stress and material condition. Based on the results of the tests and calculations, allowed defect criteria for the baseplate were recommended.

14. SUBJECT TERMS
Mortar Baseplate, Fracture Mechanics, Firing Stress, Fracture Toughness, Defect Criteria

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13. ABSTRACT *(Maximum 200 words)*

The world of interior ballistics has long been confronted with the lack of consistent time reference points. The ballistic process has no clearly defined zero time point and no clear measure of the length of the pressure pulse. The normal ballistic plot usually has a rather clear peak pressure, but without a clear zero the time-to-peak is an elusive concept. This work will demonstrate the use of mathematical functions to establish a consistent time reference zero time and a well-defined time-to-peak or time constant. These two parameters can then be combined with the nominal peak pressure, to produce nondimensional ballistic data.

14. SUBJECT TERMS
Interior Ballistics, Time Constant, Zero Time, Pressure, Time Delay

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LINEAR TIME ALGORITHMS FOR POSITIVE KERNEL SMOOTHING WITH APPLICATION TO NONPARAMETRIC PROBABILITY DENSITY ESTIMATION

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13. ABSTRACT *(Maximum 200 words)*

We present computational methods for positive kernel smoothing of piecewise linear data over uniform meshes. These methods or algorithms complete their work in an amount of time proportional to the amount of data present. The kernel used here is a B-spline which can be of arbitrarily high smoothness. The smoothed result or approximation may therefore also be as smooth as desired. The algorithms automatically evaluate the smooth approximation over any arbitrary mesh, including the original one if desired. Part of the reason why this smoothing may be done so efficiently stems from the fact that the kernel is never actually obtained or used explicitly. These methods lead naturally to consideration of smoothing the discrete cumulative distribution function corresponding to an ordered set of values of a random variable--a situation in which the original mesh is naturally always nonuniform. In this nonparametric estimation of a density, the use of a positive kernel is important, because the resulting integral smoothing operator is a monotone operator. In addition, derivatives of the smooth approximation may be obtained trivially.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Kernel, Smoothing, Nonparametric, Window	29
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STRESS DISTRIBUTION IN CONCENTRICALLY-HOLLOWED THICK-WALLED TUBES SUBJECTED TO UNIFORM RADIAL LOADING

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13. ABSTRACT *(Maximum 200 words)*

There are several industrial processes whereby thick-walled tubes are subjected to uniformly distributed radial stresses in which part of the tube's wall thickness undergoes plastic deformation, while the rest of it remains elastic. The most widely known and intensely studied of these processes is autofrettage. Autofrettage is a process whereby a thick-walled tube is subjected to internal pressurization until, hopefully, an inner sleeve undergoes plastic deformation, while an outer sleeve remains elastic. Although the investigators of this process are seeking to determine the stress distribution after depressurization, the stress distribution of the tubes under pressure and the corresponding pressure have to be determined in order to arrive at the retained stress distribution. In general, when uniformly distributed radial stresses are acting on the outer (diametrical) surface of a thick-walled tube, the tangential stress component (throughout the tube's wall thickness) has the same sign as the radial component. If, however, uniformly distributed radial stresses are acting on the inner surface of the same tube, the tangential and the radial stress components will be of the opposite sign to each other. In an elastically deformed tube, the magnitude of the tangential stress component increases towards the inner surface regardless of whether the imposed radial stress is at the outer or the inner surface, as well as with increasing magnitude of the imposed radial stress. However, if loaded at the tube's interior after plastic deformation commences, the magnitude of the tangential component decreases (from a maximum at the elastic-plastic interface) towards the tube's inner surface and in very large wall thickness tubes it might reverse its sign (at some intermediary radius between the elastic-plastic interface and the inner surface) assuming the same sign as that of the imposed radial component. In a more generalized form, the computational method used in autofrettage analysis can be utilized in the analysis of other related processes and/or products. A press-fitted concentric liner in a thick-walled tube is such an example. While the outer tube is subjected to uniformly distributed radial stresses at its bore, the liner is subjected to the same radial stresses at its outer diameter. During heat treatment of tubular components, the cooled annulus imposes a uniformly distributed radial stress on the uncooled sleeve or liner and vice versa. The equations for the calculation of the elastic-plastic interface diameter and the stresses on that surface and the equations for the stress distribution thereof in both the outer sleeve and in the plastically deformed inner sleeve of the tube are presented in this report. The calculations of the imposed radial stress(es) (internal and/or external) responsible for such a distribution are also presented here. These equations have been derived on the assumption that the material is nonstrain-hardening and isotropic and that Mises' yield criterion prevails throughout the plastic region.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Thick-Walled Tube, Pressure Vessel, Internal Pressure, External Pressure, Autofrettage Mises' Yield Criterion, Tresca's Yield Criterion, Plane-Stress, Plane-Strain	16. PRICE CODE 49

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13. ABSTRACT *(Maximum 200 words)*

The thermal oxidative stability of Fiberite 7714A (glass/epoxy), 976 (carbon/epoxy), and 977-2 (carbon/epoxy) was studied at temperatures up to and above their respective glass transition temperatures. Composite samples were subjected to both short- and long-term heating. The first set of samples was heated for 4-6 hours from 100 to 350°C, and the second set of samples was cycled for 30-minute intervals from 200 to 400°C.

The samples were tested in a Perkin-Elmer TGA7 Thermogravimetric Analyzer and weight loss recorded. Weight loss data were compared based on temperature and time at temperature. The results showed good thermal stability for each epoxy material through its glass transition temperature with a weight loss of 1.5% or less. The results were comparable for both long- and short-term temperature exposure.

14. SUBJECT TERMS
Composites, Thermal Stability, Epoxy, Decomposition

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